A Comparison of Inter- and Intraspecific Interference on Broom Snakeweed (*Gutierrezia sarothrae*) Seedling Growth

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Broom snakeweed (snakeweed) is a native range shrub found throughout semiarid rangelands of the western United States, which increases and dominates plant communities after disturbances such as overgrazing, drought, or wildfire. The objective of this study was to compare the ability of selected grass species and prostrate kochia to restrict establishment and growth of snakeweed seedlings in potted-plant and replicated field studies within two sagebrush ecological sites. In the potted-plant studies, single snakeweed seedlings were grown with seedlings (seedling neighbor study) and established plants (established neighbor study) of three cool-season grasses (crested, pubescent, and bluebunch wheatgrass), prostrate kochia, and snakeweed at increasing densities (1, 3, 5 plants/pot). Interference from crested wheatgrass in the seedling neighbor study, and both crested and bluebunch wheatgrass in the established neighbor study, induced the greatest mortality of snakeweed seedlings, and snakeweed growth was suppressed more by interspecific (grass) than intraspecific (snakeweed) neighbors in both potted-plant studies. Snakeweed establishment was also evaluated at two field sites: Howell and Nephi, UT. Snakeweed and downy brome were controlled by picloram (0.25 kg ae/ha) and glyphosate (1.5 kg ae/ha), then three native and three introduced grasses were drill-seeded, and prostrate kochia was dribble-seeded in replicated plots (3 m by 15 m) at both sites in October 2003. Snakeweed seedlings were transplanted into seeded plots and a bare ground control plot in autumn 2004. Snakeweed mortality was greatest (73%) in crested wheatgrass plots at Howell, but there were few differences among species treatments at Nephi. Of the snakeweed seedlings that survived, there was relatively little growth in any of the seeded plots compared to those in the bare ground control plots. These results indicate that seeded cool-season grasses interfered with and reduced establishment of snakeweed seedlings.

Nomenclature: Glyphosate; picloram; bluebunch wheatgrass, *Pseudoroegneria spicata* Pursh 'Goldar'; broom snakeweed, *Guterrezia sarothrae* (Pursh) Britt. & Rusby GUESA; crested wheatgrass, *Agropyron cristatum* (L.) Gaertner × *A. desertorum* (Fisch. Ex Link) Schultes 'Hycrest'; downy brome, *Bromus tectorum* L; prostrate kochia, *Kochia prostrata* (L.) Schrader 'Immigrant'; pubescent wheatgrass, *Elytrigia intermedia* ssp. *trichophorum* (Host) Beauv. 'Luna'.

Key words: Competition, restoration, weed-resistant communities, successional weed management, poisonous plant.

Broom snakeweed [*Guterrezia sarothrae* (Pursh) Britt. & Rusby] is an aggressive sub-shrub that is native to arid and semiarid rangelands of western North America. It often increases following disturbances, such as overgrazing, drought, or wildfire (Pieper and McDaniel 1989), and can dominate plant communities, reducing species diversity and forage for livestock and wildlife. Its early

spring growth allows snakeweed to compete with desirable forage species by depleting available soil moisture (Wan et al. 1993c). It is also toxic, causing abortions in livestock (Dollahite and Anthony 1957). The intent of this research was to control snakeweed and replace it with a stable, highly productive plant community that will resist future snakeweed invasion.

Snakeweed can be controlled by herbicides (McDaniel and Duncan 1987) and prescribed burning (McDaniel et al. 1997). However, to ensure the long-term success of snakeweed control efforts, managers must establish functional plant communities that compete with snakeweed and restrict its reestablishment. Recent rangeland invasive weed control theory suggests that vigorous perennial species and morphologically diverse functional groups are neces-

Interpretive Summary

Broom snakeweed is an aggressive native range weed that thrives after disturbances such as overgrazing, drought, or wildfire. Snakeweed can be controlled by herbicides and prescribed burning; however, managers must establish functional plant communities that will compete with snakeweed and restrict its reestablishment. The objective of this study was to compare the ability of selected grass species and prostrate kochia to restrict establishment and growth of snakeweed seedlings in potted-plant studies and in replicated field studies. Interspecific interference from grasses caused greater mortality and reduced growth of snakeweed seedlings compared to intraspecific interference from snakeweed neighbors in the potted-plant studies, or with no competition to snakeweed seedlings in the bare ground plots in the field study. Snakeweed seedlings appear to be sensitive to competition from other established plants. If cool season grasses can be established, they will likely utilize the available soil moisture and nutrient resources and prevent establishment of snakeweed seedlings.

sary to fully sequester soil moisture and nutrients in weed-resistant plant communities (Davies et al. 2007; Mangold et al. 2007; Sheley and Krueger-Mangold 2003; Svejcar 2003). However, some studies have demonstrated that singularly planted species with traits for rapid vigorous growth can also interfere with weed dominance (Asay et al. 2003; Monaco et al. 2003; Rose et al. 2001). Plant species or mixtures that rapidly establish and utilize available soil moisture and nutrients have the greatest potential to suppress weeds (e.g., Waldron et al. 2005). Therefore, the first step in revegetation efforts is to characterize the ability of desirable species to suppress the specific weed (Call and Roundy 1991).

The specific objective of this study was to compare the ability of cool-season grasses and prostrate kochia [*Kochia prostrata* (L.) Schrader] to restrict establishment and growth of snakeweed seedlings. These species grow rapidly in spring and early summer and compete directly with snakeweed for soil moisture and nutrients. We hypothesize that (1) cool season grasses and forage kochia will interfere with snakeweed seedling growth and reduce its establishment, and (2) that interspecific interference will cause higher mortality and lower growth of snakeweed seedlings than intraspecific interference.

Methods and Materials

Potted-Plant Studies. Five species were selected for the two potted-plant studies: 'Hycrest' crested wheatgrass [*Agropyron cristatum* (L.) Gaertner × *A. desertorum* (Fisch. Ex Link) Schultes], an early-maturing, drought-resistant, introduced bunchgrass; 'Luna' pubescent wheatgrass [*Elytrigia intermedia* ssp. *trichophorum* (Host) Beauv.], an easily established, rhizomatous introduced grass that matures in mid season; 'Goldar' bluebunch wheatgrass (*Pseudoroeg-neria spicata* Pursh), an early maturing, native bunchgrass; 'Immigrant' prostrate kochia, an introduced perennial shrub; and broom snakeweed. Seed varieties were from certified sources (quality and germination were tested) that are readily available from commercial seed companies. Broom snakeweed seed was hand-collected from the Howell site in autumn 2003.

The target neighbor design (Gibson et al. 1999; Goldberg and Fleetwood 1987) was used to determine interference in both studies. In this design, a single target snakeweed seedling was grown in the center of a pot with one, three, or five neighbor plants located 8 cm (3 in) from it around the perimeter of the pot.

The seedling neighbor study was conducted in a greenhouse at the U.S. Department of Agriculture-Agricultural Research Service, Forage and Range Research Lab in Logan, UT, without supplemental lighting. Air temperatures were maintained between 18 and 23 C (64 and 73 F) with an evaporative cooling system. Eight-L (2.1 gal) pots (21.5-cm diameter by 20.5-cm high) were filled with a soil mixture of 5 parts Kidman fine sandy loam soil and 1 part peat moss. Seeds of the neighbor species and target snakeweed were planted at 1-cm depth in the soil on April 8, 2004. Following germination, plants were thinned by pinching off the stem to attain the desired densities for the target and neighbor plants. Pots were given 500 ml of water daily and 54 ml of an all purpose fertilizer (15–30–15) weekly during the establishment phase. During the water restriction phase (July 29 to September 9), the water application rate was reduced to 75 ml/day to induce interference between the target and neighbor plants. Pots were systematically moved around the greenhouse biweekly to reduce microenvironmental effects on plant growth. The target snakeweed seedlings were harvested September 9.

In the established neighbor study, the neighbor species were planted February 17, 2004, to allow them to establish before the snakeweed target seedlings, which were planted on April 8. Pots were watered and fertilized as in the first study. Due to greenhouse space constraints, pots in this study were moved to a shade quonset (5-m height by 5-m width by 40-m length) on June 22. A shade fabric was placed over the Quonset to reduce incident radiation by 50% to prevent overheating and high transpiration from pots. The water restriction phase was the same as in the first study (July 29 to September 9) where water was reduced to 75 ml/day. Target snakeweed seedlings were harvested September 9.

The seedling neighbor and established neighbor studies were replicated in 2005. The established neighbor plants were planted on April 21, and the target snakeweed seedlings were planted on July 5. The pots were moved to the shade Quonset on September 9. Water restriction began on September 26, and the target snakeweed seedlings

were harvested on October 25. In the seedling neighbor study, both neighbors and the target snakeweed seedlings were started on July 6 and the pots remained in the greenhouse. Water restriction and harvest were the same as in the established neighbor study.

Mortality of the target snakeweed seedling and aboveground biomass was recorded at the end of both studies. The target snakeweed seedlings were harvested, dried at 45 C for 48 h, and weighed to determine aboveground biomass. Plant height and number of leaves were measured prior to imposing the water reduction, and again when the study was terminated. The initial values for height and leaf number were subtracted from the ending values, and the resulting differences were the response variables (Δ height and Δ leaf).

Data for the two studies were analyzed separately. Mortality of the target snakeweed seedlings in both studies was analyzed by a chi-square exact test. A two-way–cross-tabulated table compared species treatments for each level and across all levels, and for levels of each treatment and across all treatments. Differences among treatments were determined by two-way comparison between all possible treatment combinations.

The growth data of surviving plants were analyzed using a one-way factorial design in a mixed model ANOVA in SAS (2003). The neighbor species was the main effect, and the neighbor density (one, three, and five plants/pot) was the level for each species. There were eight replicates of each species by density treatment combination resulting in 128 pots/experiment $\cdot$ year^{-1}. Year, species, and density were considered fixed-effects factors, while the pot by year, species, and density interactions were considered random-effects factors. Differences between treatments were determined using PD 800 Macro in SAS (Saxton 1998) at $\alpha = 0.05$. A separate mixed one-way ANOVA compared interspecific interference (grass and kochia neighbors with target snakeweed seedlings), intraspecific interference (snakeweed neighbors with target snakeweed seedlings), and no interference (target snakeweed seedlings growing by themselves), and differences were determined using PD 800 Macro in SAS (Saxton 1998) at $\alpha = 0.05$.

Field Study. Two sites were selected for this study. The Howell site was located 18 km west of Tremonton, Utah (N 41° 42.8297′, W 112° 24.7745′, zone 12) on a west-facing slope at a 1,420-m elevation. The long-term average annual precipitation was 350 mm, with 50% falling from October to June (Chadwick 1975). The soil was a loamy-skeletal, mixed, mesic, Calcic Haploxeroll (Hupp gravely silt loam) (Chadwick 1975). This site was originally dominated by bluebunch wheatgrass and Wyoming big sagebrush (Artemisia tridentata var. wyomingensis Beetle & A. Young), but had been degraded by heavy spring grazing and was dominated by sagebrush, broom snakeweed,

downy brome (Bromus tectorum L.), and redstem filaree [Erodium cicutarium (L.) L'Her.]. The area was burned by a wildfire in 1985, after which snakeweed increased and dominated the site.

The Nephi site was located 8 km west of Nephi, Utah (N 39° 42.2664′, W 111° 54.9103′, zone 12) on an east-facing slope on an alluvial fan. Elevation was 1,542 m and average annual precipitation was 300 mm, with 67% falling between October and April (Trickler 1984). The soil was a fine loamy, mixed Xerolliccalciorthid (Firmage gravely loam, dry) (Trickler 1984). The plant community was originally dominated by Indian ricegrass (Stipa hymenoides R. & S.) and Wyoming big sagebrush. The area was burned in 1996, which removed most of the sagebrush, and snakeweed increased and dominated the site. Downy brome and Sandberg bluegrass (Poa secunda Presl) were dominant grasses, but there were remnants of Indian ricegrass and needle-and-thread grass (Hesperostipa comata Trin. & Rupr.). There were a few forbs present on the site, including sego lily (Calochortus nuttallii T.&G.) and scarlet globe mallow [Sphaeralcea coccinea (Nutt.) Rydb.].

Seeding treatments included three introduced grass species (Hycrest crested wheatgrass, a bunchgrass; 'Bozoisky' Russian wildrye [Psathyrostachys junceus (Fisch.) Nevski], a late-maturing, drought-resistant bunchgrass; and Luna pubescent wheatgrass, a rhizomatous grass); three native grasses ('Sand Hollow' squirreltail [Elymus multisetus (J.G. Sm.) Jones], an easily established, short-lived bunchgrass; 'Rosanna' western wheatgrass [Pascopyrum smithii (Rybd.) A. Love], a rhizomatous grass; and Goldar bluebunch wheatgrass, a bunchgrass), and Immigrant prostrate kochia, a vigorous, drought resistant sub-shrub. These species are commonly used in rehabilitation of degraded semiarid rangeland sites.

The study was a randomized complete block design with four blocks at two locations. Each block had nine plots (3 m by 15 m): seven species treatments and two control plots (a snakeweed control plot and an untreated control plot).

Site preparation included spraying plots with 0.25 kg ae/ha picloram (McDaniel and Duncan 1987; Whitson and Ferrell 1989) and 1.5 kg ae/ha of glyphosate to remove the existing vegetation in May 2001. Snakeweed control plots were sprayed with 0.25 kg/ha of picloram to kill the snakeweed without harming the grasses, and the untreated control plots were not sprayed.

Grass seed was obtained from a commercial dealer and was certified for quality and germination. Grasses were seeded in October 2001 with a five-row flex planter equipped with 2.5-cm depth bands to ensure consistent seeding depth. The row spacing was 30 cm. Seeding rate for the grasses was 6 to 8 kg/ha of pure live seed. The low precipitation on these sites would not support a stand seeded at higher rates (Howard Horton, personal commu-

nication). The seeding failed to establish the first year due to drought. Treatment plots in both locations were sprayed again in April 2002 with 1.5 kg ae/ha of glyphosate in an attempt to control emerging downy brome, and again in October 2002, with 0.2 kg ae/ha of imazapic to control downy brome and other annual weeds prior to reseeding. A second seeding was attempted in fall 2002, but it also failed because of drought. The few weeds that did emerge in the treatment plots were removed with a shovel in fall 2003. A third seeding was repeated in October 2003, and was successful. Prostrate kochia was seeded in March 2004 by dribbling seed on the soil surface at a rate of 5 kg/ha with the same 5-row flex planter, but it did not establish. It was reseeded with a dribbler cart in December 2004 and it emerged in spring 2005.

Establishment was poor for kochia and western wheatgrass at both locations, and Russian wildrye at Nephi. These treatments did not establish three solid rows of seeded plants that was necessary for the design for establishing snakeweed seedlings in the field. Thus, these treatments were not included in the field snakeweed seedling establishment trial.

Snakeweed seedlings were germinated in cone-tainers (5-cm diameter by 16-cm depth) in a greenhouse in July 2004. On September 10, these seedlings were transplanted into two, 1-m^2 subplots within the larger treatment plots. The two 1-m^2 subplots were placed over three uniform rows of seeded grasses in each treatment plot. In each subplot, three snakeweed seedlings were planted 25 cm apart in each of the two interspaces between the three seeded rows (six snakeweed seedlings/subplot). Subplots were also established in the snakeweed control plots where downy brome dominated, and in bare ground plots (two for each block) established outside each of the four blocks. The bare ground plots were sprayed with glyphosate (1.5 kg ae/ha) in early September 2004 to eliminate all competition to the snakeweed seedlings.

Snakeweed seedlings were watered weekly until mid-October when autumn precipitation was able to sustain the seedlings. Seedlings that died were also replaced each week up to mid-October to ensure there were six plants in every quadrat. Extra seedlings were kept in cone-tainers in the greenhouse over winter and planted in April 2005 to replace those that died in the field during the winter. In spite of the different over-wintering environments, snakeweed seedlings were similar in size when measurements began in early summer.

The species treatments were evaluated to determine their ability to suppress snakeweed seedling growth. Mortality of snakeweed seedlings was recorded at the end of the summer, and surviving snakeweed seedlings were harvested, dried (at 40 C for 48 h) and weighed to determine aboveground biomass.

End of season mortality was analyzed by a chi-square exact test in a two-way cross-tabulated table that compared treatments. Treatments differences were determined by two-way comparison of all possible treatment combinations. A mixed model ANOVA was used to analyze seedling biomass. The large seeding plots were the experimental units. Seed species treatments and study sites were the fixed factors, and blocks were the random effects. Differences between treatments were determined using PD800 Macro in SAS (Saxton 1998) at $\alpha = 0.05$.

Results

Potted-Plant Studies. There was a year-by-treatment interaction ($P < 0.001$) of all response variables in the established neighbor study. There was very little growth of the target snakeweed seedlings in this study in 2005, thus the response to interference treatments was negligible and erratic. Therefore, only the 2004 data will be discussed in the established neighbor study. We suspect that the growing conditions in September and October 2005 outside under the shade canopy were not conducive for snakeweed seedling growth.

Target seedling mortality was greater in the established neighbor study than the seedling neighbor study, presumably due to the greater water use by established grasses. Snakeweed target seedling mortality ranged from 10 to 30% among the grasses in the seedling experiment, and from 22 to 70% in the established neighbor experiment (Table 1). Mortality was greatest from crested wheatgrass neighbors in the seedling neighbor study, and from bluebunch and crested wheatgrass in the established neighbor study. Although pubescent wheatgrass is rhizomatous, it did not compete with snakeweed as well as the bunchgrasses. There was no snakeweed seedling mortality in the kochia treatments in either study. Only one target snakeweed seedling died with snakeweed neighbors.

Increasing neighbor density did not influence any of the target snakeweed seedling response parameters in either study ($P > 0.13$). Aboveground biomass of the grass neighbors did not differ among density levels in the seedling neighbor study ($P > 0.41$, data not shown). There were a few differences in aboveground biomass in the established neighbor study ($P < 0.002$, data not shown), but they were not proportional to the number of plants. Regardless of the number of neighbor plants, their roots apparently sequestered the limited amount of water during the water restriction phase, causing similar interference of the target snakeweed seedlings.

There were few minor differences in the growth parameters of snakeweed target seedlings among the grass and kochia treatments in either seedling or established neighbor studies (Table 1), but they all differed from the

Table 1. Mortality and vigor measurements of target snakeweed seedlings in the seedling neighbor (Seed.) and established neighbor (Estab.) studies. Change in snakeweed target seedling height (Δ Height) and number of leaves (Δ Leaves) during the water restriction phase of the studies, and aboveground biomass of target seedling at the end of the studies.

Treatment	Mortality[a]		Δ Height[b]		Δ Leaves[b]		Biomass[b]	
	Seed.	Estab.	Seed.	Estab.	Seed.	Estab.	Seed.	Estab.
	————— % —————		————— cm —————		————— n —————		————— g/plant —————	
Crested wheatgrass	30 a	57 a	0.88 b	−0.02 b	10.1 b	−1.3 b	0.07 b	0.01 b
Pubescent wheatgrass	21 ab	22 b	0.85 b	0.03 b	10.6 b	0.3 b	0.07 b	0.03 b
Bluebunch wheatgrass	10 b	70 a	1.69 b	−0.03 b	18.6 ab	−1.5 b	0.14 ab	0.02 b
Kochia	0 c	0 c	0.77 b	0.27 b	16.5 ab	1.4 b	0.11 b	0.06 b
Snakeweed	1 c	0 c	3.69 a	0.73 a	26.3 a	11.0 a	0.21a	0.27 a

[a] Mortality data analyzed by chi-square exact test.

[b] Change in height, number of leaves, and biomass data analyzed by mixed model ANOVA.

*Values within columns followed by different letters differ (P < 0.05).

snakeweed neighbor treatment (P < 0.02). Thus, there were differences in target seedling growth between interspecific interference (grasses and kochia vs. snakeweed target seedling) and intraspecific interference (snakeweed vs. snakeweed target seedling) in both potted-plant studies (Figure 1). In the seedling neighbor study, target snakeweed height increased 3.69 cm when grown with snakeweed neighbors, compared to only 1.0 cm with grass or kochia neighbors (P = 0.0001). Only 14 leaves were added to the target snakeweed seedlings with interspecific neighbors, compared to 26 leaves with intraspecific neighbors (P = 0.005). Biomass was also less with interspecific neighbors, compared to intraspecific neighbors (P = 0.0007).

In the established neighbor study, target snakeweed seedlings grew poorly with established neighbors (Figure 1). Interspecific neighbors (grasses and kochia) suppressed height (P < 0.001), number of leaves (P < 0.001) and biomass (P < 0.001) of target snakeweed seedlings to a greater extent than intraspecific (snakeweed) neighbors.

Field Studies. Snakeweed seedling mortality differed among the seeded species treatments at Howell (P < 0.001) and Nephi (P = 0.01) (Table 2). At Howell, snakeweed mortality was highest in crested wheatgrass plots (73%), and lowest in bare ground plots representing no competition (20%). At Nephi, pubescent wheatgrass and downy brome in the snakeweed control plots produced the greatest mortality of snakeweed seedlings, while the bare ground plots had essentially no mortality (Table 2). Snakeweed biomass was also greater in the bare ground plots (4.07 g [0.14 oz] at Howell, 8.26 g at Nephi) compared to negligible growth in the seeded or snakeweed control plots (P < 0.01, Table 2), suggesting that competition from any vegetation suppressed snakeweed seedling growth.

Discussion

The target snakeweed seedling mortality was greater, and the growth parameters of surviving seedlings were lower, in the established neighbor study than in the seedling neighbor study. Established neighbors had been growing for 2 mo and developed extensive root systems and top growth before the snakeweed seedlings were planted. During the water restriction phase, these established grasses likely extracted more of the limited soil moisture, thus increasing interference of the snakeweed seedlings.

There was no target snakeweed seedling mortality in the kochia treatments. Although target snakeweed seedling growth was suppressed, the degree of interference did not result in death. Kochia seedlings have a single slender tap root, and it characteristically grows very slowly during the first year (Blair Waldron, personal communication). Kochia did not establish in either of the field seeding sites; therefore, its interference with snakeweed seedlings in the field could not be tested.

All of the grass and kochia neighbor treatments restricted the growth of target snakeweed seedlings, compared to the snakeweed neighbor treatments in both potted-plant studies. Furthermore, there was no intraspecific interference (snakeweed neighbor vs. target snakeweed seedling) in either potted-plant study. Target snakeweed seedling growth parameters were numerically greater when grown with snakeweed neighbors than by itself in both trials (Figure 1), but the differences were not significant (P > 0.05). Snakeweed seedling growth actually increased with increasing density of snakeweed plants in the seedling neighbor study, though the increase was not significant (P > 0.24, data not shown). These results are contrary to responses of herbaceous invasive weeds. Intraspecific interference had a greater influence than interspecific interference for seedlings of yellow starthistle (*Centaurea*

Seedling Neighbors
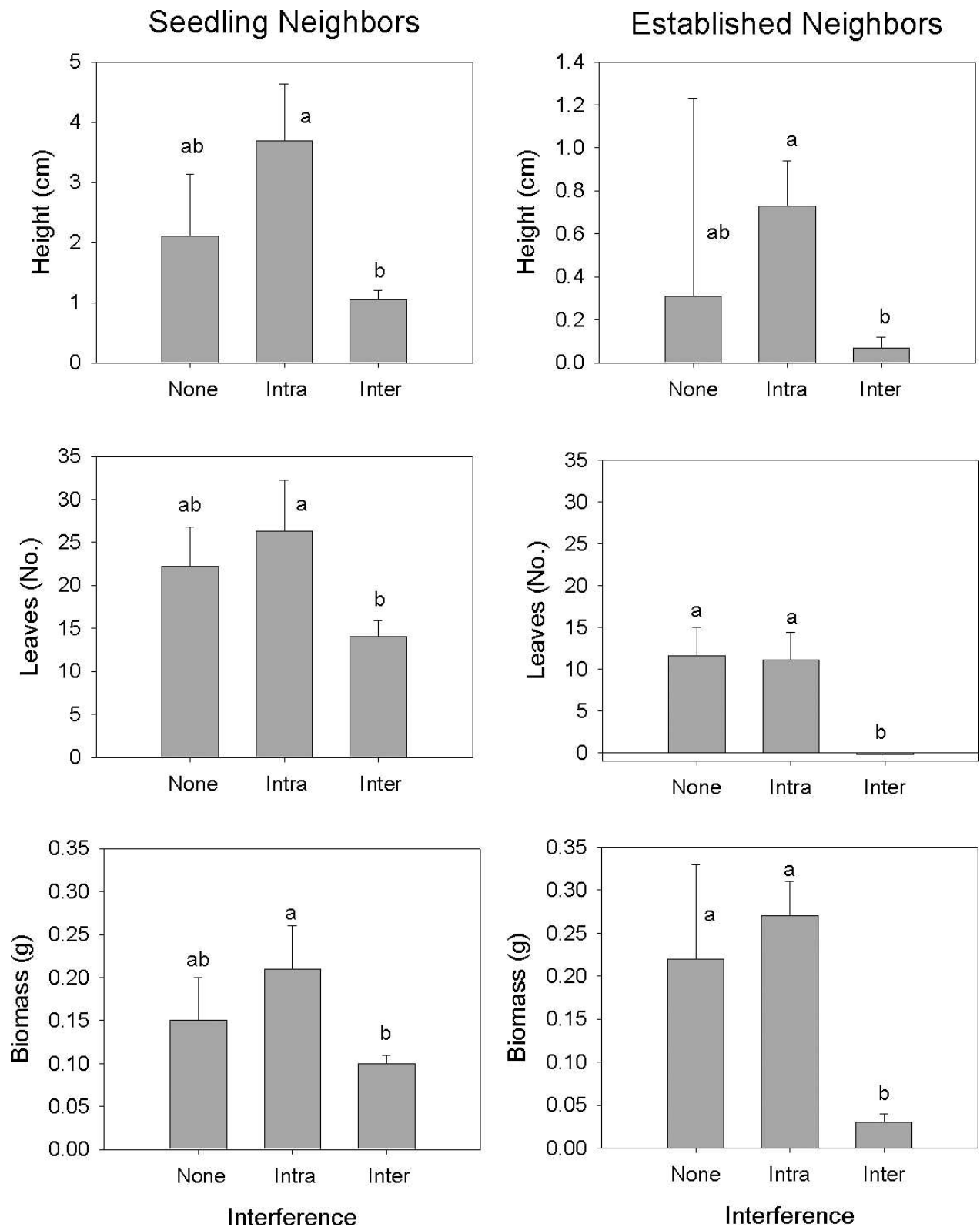
Established Neighbors

Figure 1. Growth parameters of target snakeweed seedlings when grown alone (no interference), with snakeweed neighbors (intraspecific interference), or with grass and kochia neighbors (interspecific interference) in the seedling neighbor and established neighbor studies. Error bars are standard errors. Bars labeled with different letters differ (P < 0.05).

Table 2. Mortality and biomass of remaining target snakeweed seedlings planted in seeded grass treatments at Howell and Nephi.

Treatment	Howell		Nephi	
	Mortality	Biomass	Mortality	Biomass
	%	g	%	g
Crested wheatgarss	73 a*	0.08 b	27 ab	0.50 b
Russian wildrye	48 b	0.15 b	-	-[a]
Pubescent wheatgrass	29 bc	0.04 b	45 a	0.96 b
Squirreltail	40 b	0.39 b	21 b	1.47 b
Bluebunch wheatgrass	38 bc	0.24 b	22 ab	0.52 b
Snakeweed control	29 bc	0.20 b	44 a	0.63 b
Bare ground	20 c	4.07 a	2 c	8.26 a

[a] Russian wildrye did not establish well at Nephi; thus, it was not included in the snakeweed transplant trial.

* Means within columns followed by different letters differ (P < 0.05).

solstitialis L.) vs. pubescent wheatgrass (Prather and Callihan 1991), spotted knapweed (*Centaurea stoche* L.) vs. intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D. R. Dewey] (Velga et al. 1997), and diffuse knapweed (*Centaurea diffusa* Lam.) vs. blue-bunch wheatgrass (Larson and Kiemnec 2003). Differences in root morphology of the forb species provided more interference within species than between species, and the deeper penetrating roots of the forbs generally produced more interference toward the grasses. The single tap root of snakeweed seedlings appears to not be very competitive with other species.

Our results suggest that there may be an advantage for snakeweed seedlings to grow in the presence of other snakeweed seedlings. There is abundant empirical evidence of flushes of snakeweed seedlings emerging during periods of high precipitation following disturbances of drought (McDaniel 1989; McDaniel and Ross 2002; Ralphs and Sanders 2002), fire (Thacker et al. 2008), herbicide control (McDaniel et al. 2000), and grazing (Ralphs and Banks 2009). These disturbances can reduce competition from other vegetation as well as established snakeweed plants. When favorable environmental conditions return (warming soil temperatures [Mayeaux and Leotta 1981] and saturated soil surface for at least 4 d [Wood et al. 1997]), snakeweed seedlings can germinate, establish, and create even-aged stands that dominate the plant community.

The seeded grasses in the field trials had been established for a year, and the snakeweed seedling transplants were placed between solid rows of the grasses. Crested wheatgrass produced the highest mortality of snakeweed seedlings at Howell, and pubescent wheatgrass produced highest mortality of snakeweed seedlings from among the seeded grass treatments at Nephi. Downy brome was the dominant species in the snakeweed control plots at Nephi, and also caused high mortality of snakeweed seedlings. The greatest survival and subsequent growth of snakeweed seedlings occurred in the bare ground plots representing no interference.

Results of both our potted-plant and field studies suggest that these cool season grasses interfered with snakeweed seedling establishment. Snakeweed seedlings appear to be sensitive to competition from all established vegetation, including downy brome. Likewise, Ralphs et al. (2007) reported that cool season grasses suppressed establishment of white locoweed (*Oxytropis sericea* Nutt. ex T&G) seedlings. Davies (2008) reported a negative correlation between large, cool-season perennial bunchgrass density and establishment of medusahead [*Taeniatherum caput-medusae* (L.) Nevski]. He suggested that tall tussock perennial grasses are critical to preventing medusahead invasion. Grass species that establish rapidly and produce the greatest biomass interfered with and suppressed annual grasses and weeds (Borman et al. 1991; Waldron et al. 2005), diffuse knapweed, and yellow starthistle seedlings (Larson and McInnis 1989).

Although snakeweed seedlings are sensitive to interference from grasses during establishment, once they become established, they are highly competitive with coexisting grasses (McDaniel et al. 1982; Ueckert 1979). In the Southwest United States, snakeweed is evergreen, resuming new growth from the crown following flowering in the fall. Plants are mature and fully developed when warm-season grasses resume growth in late spring. In northern climates, snakeweed begins growth early in the spring. As summer drought progresses, grasses go dormant while snakeweed remains green and turgid. Furthermore, snakeweed stomata do not close completely under water stress (DePuitt and Caldwell 1975; Wan et al. 1993a), so its luxuriant use of water continues. If water stress is severe, it sheds leaves, but stems continue photosynthesis, providing for respiration, flowering, and seed production (Wan et al. 1993b). Once established, snakeweed is very competitive and will likely remain a dominant species in the plant community.

There appears to be a window of opportunity for grasses to suppress snakeweed in its seedling stage, if the grasses can be established. Therefore, if perennial grasses are not abundant following disturbance (wildfire, drought, or snakeweed control), cool-season grasses should be seeded in an attempt to establish a solid stand that will prevent snakeweed establishment and subsequent domination in the plant community. If seeded species do not establish, downy brome will likely fill in and dominate, but it also appears to suppress snakeweed seedlings after it is established. Crested wheatgrass consistently established in our field studies, and provided the greatest suppression of snakeweed establishment and growth in both our potted plant and field trials.

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